ASSESSMENT OF GREENLAND TURBOT STOCK IN THE EASTERN BERING SEA AND ALEUTIAN ISLANDS

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Summary

Relative to last year's assessment, the following changes have been made in the current assessment.

New input data

1. 2001 fishery total catch and catch-at-length by gear type,
2. EBS slope survey 2002 biomass and length composition estimate (last slope survey occurred in 1991).
3. EBS shelf survey 2002 biomass and length composition estimate.
4. Aleutian Islands survey 2002 biomass and length composition estimate (data not currently used in the main assessment),
5. An aggregated longline survey data index for the EBS and AI, and

Assessment model

This year we continued research on developing an alternative model. Part of this work involved incorporating additional data published in Russian reports since there is substantial evidence that this stock is shared between the US and Russian EEZ. Exploration the stock synthesis model that has been used since 1993 consisted of evaluating the relative weight placed on the main tuning index, the EBS slope survey, since a new survey was available from 2002.

Assessment results

The value of $B_{40\%}$ was estimated by using the mean estimated recruitment for the period 1978-1998. The results indicate that the long-term average female spawning biomass is around 54,400 tons. The current estimate of the year 2003 female spawning biomass is about 67,800 t. These values are considerably lower than last year's estimates of 80,000 for $B_{40\%}$ and 132,000 tons for 2002 spawning biomass. This is due to the fact that there is a new slope survey included in this year's assessment (and that greater emphasis was placed on fitting this survey value). Given the current model structure and general uncertainty about stock structure, we recommend an ABC based on the recent 5-year average fishing mortality **5,880 mt.** We feel that this is justified based on the projections for the anticipated further declines and the continued lack of apparent recruitment. Our recommendation for overfishing, based on the adjusted $F_{35\%}$ rate is **17,800 t** corresponding to an full-selection F of 0.32.

Introduction

Greenland turbot (*Reinhardtius hippoglossoides*) within the US 200-mile exclusive economic zone are mainly distributed in the eastern Bering Sea (EBS) and Aleutian Islands region. Juveniles are believed to spend the first 3 or 4 years of their lives on the continental shelf and then move to the continental slope (Alton et al. 1988). Juveniles are absent in the Aleutian Islands regions, suggesting that the population in the Aleutians originates from the EBS or elsewhere. In this assessment we assume that the Greenland turbot found in the two regions represent a single management stock.

Prior to 1985 Greenland turbot and arrowtooth flounder were managed together. Since then, the Council has recognized the need for separate management quotas given large differences in the market value between these species. Furthermore, the abundance trends for these two species are clearly distinct (e.g., Wilderbuer and Sample 1992).

The American Fisheries Society uses "Greenland halibut" as the common name for *Reinhardtius hippoglossoides* instead of Greenland turbot. To avoid confusion with the Pacific halibut, *Hippoglossus stenolepis*, we retain the common name of Greenland turbot which is also the "official" market name in the US and Canada (AFS 1991). For further background on this assessment and the methods used refer to Ianelli and Wilderbuer (1995).

4.1. Catch history and fishery data

Catches of Greenland turbot and arrowtooth flounder were not reported separately during the 1960s. During that period, combined catches of the two species ranged from 10,000 to 58,000 t annually and averaged 33,700 t. Beginning in the 1970s the fishery for Greenland turbot intensified with catches of this species reaching a peak from 1972 to 1976 of between 63,000 t and 78,000 t annually (Fig. 4.1). Catches declined after implementation of the MFCMA in 1977, but were still relatively high in 1980-83 with an annual range of 48,000 to 57,000 t (Table 4.1). Since 1983, however, trawl harvests declined steadily to a low of 7,100 t in 1988 before increasing slightly to 8,822 t in 1989 and 9,619 t in 1990. This overall decline is due mainly to catch restrictions placed on the fishery because of declining recruitment. For the period 1992–1997, the Council set the TAC's to 7,000 t as an added conservation measure due to concerns about apparent low levels of recruitment in the past several years. This has resulted in primarily bycatch-only fisheries. The distribution of the longline fishery (in 2000) was mainly concentrated along the slope regions while the trawl fishery catch was patchier and had highest catch rates in the southeastern area (Fig. 4.2).

Table 4.1. Catches of Greenland turbot by gear type (including discards) since implementation of the MFCMA.

Year	Trawl	Longline & Pot	Total
1977	29,722	439	30,161
1978	39,560	2,629	42,189
1979	38,401	3,008	41,409
1980	48,689	3,863	52,552
1981	53,298	4,023	57,321
1982	52,090	32	52,122
1983	47,529	29	47,558
1984	23,107	13	23,120
1985	14,690	41	14,731
1986	9,864	0	9,864
1987	9,551	34	9,585
1988	6,827	281	7,108
1989	8,293	529	8,822
1990	10,869	577	11,446
1991	9,289	814	10,103
1992	1,559	1,130	2,689
1993	1,142	7,306	8,448
1994	6,427	3,843	10,272
1995	3,978	4,214	8,193
1996	1,653	4,900	6,553
1997	1,209	6,327	7,536
1998	1,829	7,295	9,124
1999	1,710	3,917	5,627
2000	1,905	4,736	6,641
2001	2,116	3,127	5,243
2002*	900	1,600	2,500

* Estimate as of 10/14/02, source: NMFS Regional Office, Juneau, AK

Catch information prior to 1990 included only the tonnage of Greenland turbot retained onboard Bering Sea fishing vessels or processed onshore (as reported by PacFIN). However, Greenland turbot are also discarded overboard in other trawl target fisheries. The following estimates of discards from 1990-98 were estimated from a combination of discard rates observed from vessels with 100% observer sampling and NMFS regional office weekly processor reports.

Year	**Trawl**	**Longline**	**Total**
1990	na	Na	1,250 t
1991	na	Na	3,427 t
1992	na	Na	1,013 t
1993	na	Na	1,333 t
1994	854 t	1,858 t	2,711 t
1995	535 t	2,087 t	2,622 t
1996	354 t	1,042 t	1,396 t
1997	289 t	1,533 t	1,822 t
1998	140 t	661 t	801 t

Additional information on 1999-2001 retained and discarded catch of Greenland turbot indicates that a large fraction of discards occurred due to the sablefish fishery (Table 4.2). The proportion of discards attributed to the sablefish fishery increased from 17% in 1999 to about 40% in 2001.

Table 4.2. Estimates of discarded and retained Greenland turbot based on NMFS Blend estimates by fishery, 1999-2001.

	1999			2000			2001		
Fishery	Discarded	Retained	Total	Discarded	Retained	Total	Discarded	Retained	Total
G.Turbot	227	4,009	4,236	177	4,798	4,975	89	2,724	2,813
Flathead sole	56	363	420	67	510	577	138	514	652
Sablefish	120	179	300	253	192	446	373	167	540
ATF	76	131	207	93	262	355	182	201	383
P. Cod	50	180	230	108	130	238	63	185	247
Rockfish	2	25	27	1	39	39	30	431	461
A. Mackerel	42	112	154	43	161	204	21	50	72
Others	156	127	283	48	92	139	43	92	135
Total	729	5,128	5,857	790	6,183	6,973	940	4,364	5,304

Catch and catch per unit effort (CPUE)

The catch data were used as presented above for both the longline and trawl fisheries. The early catches included Greenland turbot and arrowtooth flounder together. To separate them, we assumed that the ratio of the two species for the years 1960-64 was the same as the mean ratio caught by USSR vessels from 1965-69.

A CPUE index derived in Alton et al. (1988) for the years 1978-84 for the trawl fishery was used as an index of abundance in the stock synthesis model:

Year	1978	1979	1980	1981	1982	1983	1984
CPUE Index	291	316	449	409	235	195	335

Ianelli et al. (1999) presented a preliminary examination of recent catch rate data based on the NMFS NORPAC observer database. Due to the short seasons for the directed fishery in recent years we concluded that these data are not reliable as an index of abundance.

Size and age composition

No age composition information is available from the fisheries or surveys. Survey size-at-age data were available from 1975, 1979-1982. These data are used to establish the length-age (and variability in length-at-age) within the stock assessment model. Extensive length frequency compositions have been collected by the NMFS observer program from the period 1980 to 1991. The length composition data from the trawl and longline fishery and the expected values from the assessment model are presented in previous assessments. This information is used in the assessment model and adds to our ability to estimate size-specific selectivity patterns in addition to year-class variability.

4.2. Resource Surveys

Abundance estimates for juvenile Greenland turbot on the EBS shelf are provided annually by AFSC trawl surveys. The older juveniles and adults on the slope were assessed every third year from 1979-1991 (also in 1981) during U.S.-Japan cooperative surveys. The slope surveys were conducted by Japanese shore-based (Hokuten) trawlers chartered by the Japan Fisheries Agency until 1985. In 1988, the NOAA R/V Miller Freeman surveyed the resources on the EBS slope region. In this same year, chartered Japanese vessels performed side-by-side trawl experiments with the Miller Freeman for calibration purposes. Due to limited vessel time, the area and number of stations sampled by the Miller Freeman was less than sampled by the Japanese trawlers in most previous years. The Miller Freeman sampled 133 stations over a depth interval of 200-800 m while during earlier slope surveys the Japanese vessels usually sampled 200-300 stations over a depth interval of 200-1,000 m (Table 4.3).

We believe that the U.S. and Japanese trawl slope-surveys under-estimate the actual biomass of Greenland turbot when swept-area expansions are made. Thus, we treat these as indices of relative abundance. That is, the species appears to extend beyond the area of the survey and that the ability to tend bottom in the deeper waters may be compromised.

The AFSC instituted a bottom trawl survey of the upper continental slope of the eastern Bering Sea in 2002. This survey will be conducted biennially. The benthic resources of the eastern Bering Sea continental slope have been explored with bottom trawls in prior years (1979-1991). The 2002 survey will initiate a time series of trawl survey results that will provide information on abundance trends and trends in the biological condition of the groundfish and invertebrate resources in that habitat.

A new slope survey was conducted during the summer of 2002. Based on the 2000 pilot survey, a Poly Noreastern trawl with a mud-sweep footrope was selected for the 2002 survey. The stations were randomly selected within depth and area strata. A total of 137 sampling locations were completed with Greenland turbot catch rates shown in Fig. 4.3.

The combined estimates from the shelf and slope indicate a decline in EBS abundance for the 4 years of observations that were available during 1979-1985. After 1985, the slope biomass estimates (and the 1991 Aleutian Islands estimate) are not comparable to previous years due to differences in depths sampled. The interpretation of the CPUE data from these surveys, however, suggests a moderate decline in abundance between 1985 and 1991. The average shelf-survey biomass estimate during the last 9 years (1993-2001) is 29,968 tons with a declining trend during this period.

The following table summarizes the sampling that has occurred for the EBS bottom trawl survey data since 1982:

Year	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
No. hauls	329	354	355	353	354	342	353	353	352	351
No. Lengths	969	951	536	196	195	82	200	183	232	360
Year	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**
No. hauls	336	355	355	356	355	356	355	353	352	355
No. Lengths	440	400	398	313	297	197	93	207	248	274

Biomass estimates from U.S.-Japan cooperative surveys in the Aleutian Islands region suggest an increasing trend from 48,700 t in 1980 to 76,560 t in 1986 (the 1991 estimate is not directly comparable). Relative to the trend in the EBS, the apparent increased abundance in the Aleutian Island Region may be due to migration of older fish from the EBS. In 1997 NMFS AFSC conducted a triennial bottom-trawl survey of the Aleutian Islands region using methods described in Harrison (1993). The preliminary area-swept estimate of biomass from this survey is 32,027 tons. This compares with a value of 29,106 tons estimated from the 1994 survey. Examining the distribution of where the survey found Greenland turbot in the Aleutian Islands reveals similar patterns between the 1994 and 1997 surveys.

Previously, the eastern Bering Sea Cooperative longline survey was incorporated for use as a relative abundance index. This survey covered a larger portion of the slope and shelf area than the present longline survey. A bootstrap resampling scheme was used to provide confidence bounds on the annual relative abundance estimates. We used the median values of the bootstrap estimates as our relative population index. This index represents numerical abundance whereas the shelf and slope surveys represent biomass indices. We continue to work on methods of incorporating recent domestic longline surveys which, beginning in 1996, have been extended into the Bering Sea and part of the Aleutian Islands (in alternate years). This new sampling area represents a smaller region than in past but shows that about 25% of the population along the slope regions is found within the northeast (NE) and southeast (SE) portions of the Aleutian Islands compared to the abundances along the slope of the EBS:

Relative Population No. (RPN)	**Year**

Area	1996	1997	1998	1999	2000	2001	2002
Bering 4		11,729		13,072		16,082	
Bering 3		6,172		6,156		5,005	
Bering 2		27,936		33,848		24,766	
Bering 1		13,491		10,068		4,788	
NE Aleutians	23,133		17,120		12,987		10,942
SE Aleutians	2,142		1,806		1,201		1,397
Bering Sea		59,328		63,144		50,641	
Aleutians	25,275		17,930		14,188		12,339
Combined	88,022	83,226	62,441	88,579	49,411	71,040	42,970

The combined time series shown above (1996-2002) was used as a relative abundance index (Fig. 4.4). It was computed by taking the average RPN from 1996-2002 for both areas and computing the average proportion. The combined *RPN* in each year (RPN_t^c) was thus computed as:

$$RPN_t^c = I_t^{AI} \frac{RPN_t^{AI}}{p^{AI}} + I_t^{EBS} \frac{RPN_t^{EBS}}{p^{EBS}}$$

where I_t^{AI} and I_t^{EBS} are indicator function (0 or 1) depending on whether a survey occurred in either the Aleutian Islands or EBS, respectively. The average proportions are given here by each area as: p^{AI} and p^{EBS} . Note that each year data are added to this time series, the estimate of the combined index changes (slightly) in all years.

Table 4.3. Survey estimates of Greenland turbot biomass for the Eastern Bering Sea shelf and slope areas and for the Aleutian Islands region, 1975-2002.

	Eastern	Bering Sea		Aleutians
Year	Shelf	Slope	Shelf and Slope Combined	
1975	126,700	---	---	---
1979	225,600	123,000	348,600	---
1980	172,200	---	---	48,700
1981	86,800	99,600	186,400	---
1982	48,600	90,600	139,200	---
1983	35,100	---	---	63,800
1984	17,900	---	---	---
1985	7,700	79,200	86,900	---
1986	5,600	---	---	76,500
1987	10,600	---	---	---
1988	14,800	42,700*	57,500*	---
1989	8,900	---	---	---
1990	14,300	---	---	---
1991	13,000	40,500	53,900*	11,925**
1992	24,000	---	---	---
1993	30,400	---	---	---
1994	48,800	---	---	28,227**
1995	34,800	---	---	---
1996	30,300	---	---	---
1997	29,218	---	---	28,334**
1998	28,126	---	---	---
1999	19,797	---	---	---
2000	22,957	---	---	9,359**
2001	25,311	---	---	---
2002	21,616	27,589	49,205	9,891**

* The 1988 and 1991 estimate are from 200-800 m whereas earlier (and 2000) slope estimates are from 200-1,000 m.
** The 1980, 1983, and 1986 surveys sampled 1-900 m whereas the 1991 - 2002 surveys sampled only 1-500 m.
*** Based on a preparatory survey using mudsweep footrope. These data were not used in the assessment model. See text for further details.

A time series of estimated size composition of the population was available for the shelf and slope trawl surveys and for the longline survey. The slope surveys typically sample more turbot than the shelf trawl surveys; consequently, the number of fish measured in the slope surveys is greater. The time series of length frequencies from the longline survey was presented in Ianelli et al. (1994). The Greenland turbot size composition from the 2002 shelf trawl survey is given in Fig. 4.5 while for the new slope survey the length frequencies are given in Fig. 4.6.

Scientific research catches are reported to fulfill requirements of the Magnuson-Stevens Fisheries Conservation and Management Act. The following table documents annual research catches (1977 - 1998) from NMFS longline and trawl surveys (in tons):

Year	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
NMFS Bottom trawl surveys	62.48	48.36	103.01	123.6	15.14	0.73	175.22	72.84	0.56	18.48
Domestic Longline surveys	NA									
Cooperative Longline surveys	3	3	6	11	9	7	8	7	11	6
Year	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**
NMFS Bottom trawl surveys	0.64	0.85	11.37	0.88	1.43	8.51	1.44	1.47	4.64	1.38
Domestic Longline surveys										
Cooperative Longline surveys	16	10	10	22	23	23				

4.3. Model Structure

The use of the stock synthesis program (Methot 1990) to model the eastern Bering Sea component of Greenland turbot stock was presented in previous assessments (Ianelli et al. 1994, 1995). Before 1994, stock assessments of Greenland turbot in the eastern Bering Sea and Aleutian Islands have relied in part on stock reduction analysis (SRA) to provide historical trends in the fishery (Wilderbuer and Sample 1992). This year efforts were begun to simplify the model used for Greenland turbot. A functional, two-fishery combined-sexes model is complete and appears to have the same general patterns of recruitment and abundances when fit to the same length and survey indices. However, further model specification issues need to be addressed before it can be used extensively. For example, inconsistencies with the data seem to become more obvious. Thus, we feel that more consideration of how the data are used is needed before an appropriate model can be developed. As with past years, the length-version of the stock synthesis program (Methot 1990) was used for this assessment. Catch data used in the stock synthesis model were from 1960 to 2002. The last eight years were adjusted to include discards. It was assumed that the stock was at or close to its virgin biomass level at the beginning of the catch data time series.

Model parameters are estimated by maximizing the log likelihood (L) of the predicted observations given the data. Data are classified into different components. For example, age composition from a survey and catch per unit effort (CPUE) from a fishery are different components. The total L is a sum of the likelihoods for each component. The total L may also include a component for a stock-recruitment relationship and penalty functions to help stabilize parameter estimates. The likelihood components may be weighted by an emphasis factor. For Greenland Turbot in the EBS the model included two fisheries, those using longline and trawl gear, and three surveys. Table 4.4 summarizes the extent of the data used in the different likelihood components. Since a new slope-survey data point was available in the current year, and given that this has been considered an important habitat area for Greenland turbot, extra "emphasis" was placed on this survey (a factor of 10) so that the model would be tuned to this abundance index.

Table 4.4. Data sets used in the stock synthesis model for Greenland Turbot in the EBS. All size and age data are specified by sex.

Data Component	Years of data
Survey Size at age data	1975, 1979-82
Shelf Survey: size composition and biomass estimates	1979-2002
Slope Survey: size composition and biomass estimates	1979, 81, 82, 85, 88, 91, 2002
Longline Survey: size composition and abundance index	1996-2002
Total Fishery Catch Data	1960-2002
Trawl CPUE Index	1978-1984
Trawl Catch Size Composition	1977-87, 1989-91, 1993-2001
Longline Catch Size Composition	1977, 1979-85, 1992-2001

Annual recruitments are estimated as parameters in the model, they can be thought of as "anomalies" from an underlying stock-recruitment curve. These recruitment anomalies can be due to process and observation errors. Process errors refer to the real differences from the mean stock-recruitment curve caused by natural variation in recruitment success. Observation errors refer to our ability to estimate the true recruitment levels due to sampling problems. In this application, observation error is considered negligible compared to the magnitude of recruitment variability (process error). Consequently, the underlying parameters of the stock-recruit curve play an insignificant role in fitting the model to the data. For further details on the model specifications of the length-version of the stock synthesis program, see Thompson *et al.* (Pacific cod chapter, this volume).

Selectivity Patterns

A dome-shaped size-based selectivity function (Methot 1990) was estimated for each survey and fishery described below. For the trawl fishery, the periods of length frequency data collections from the domestic and foreign fleet did not overlap. Consequently, we treated the foreign and domestic trawl data as from a single fishery and simply let the selectivity pattern be different between the respective periods. Because larger fish have been observed in the recent EBS shelf region trawl surveys, selectivity was also was estimated separately for two periods: 1994-present and 1982-1993.

4.3.1. Parameters estimated independently

Natural mortality, length at age, length-weight relationship

The natural mortality of Greenland turbot was assumed to be 0.18. This estimate was used because it is slightly less than that of other flatfish species with a slightly lower maximum age. Greenland turbot taken by the commercial fishery have been aged as old as 21 years.

Parameters describing length-at-age are estimated within the model. We do assume that the length at age 1 is the same for both sexes and that the variability in length at age 1 has an 8% CV and that the variability in length at age 21 has a CV of 7%. This appears to encompass the observed variability in length-at-age.

As in the previous assessments, size-at-age information from surveys conducted between 1976-82 were used in the model to help estimate the relationship between age and length. The length-weight relationship for Greenland turbot estimated by Ianelli et al. (1993) was:

$$w = 2.69 \times 10^{-6} L^{3.3092} \quad \text{for females}$$

and

$$w = 6.52 \times 10^{-6} L^{3.068} \quad \text{for males}$$

where L = length in mm, and w = weight in grams.

Maturation and fecundity

Maturation and fecundity by size or age is poorly understood for Greenland turbot. Alton *et al.* (1988) present the results from studies of Greenland turbot in different areas in addition to the EBS region. For this analysis, we chose a logistic size-maturity relationship which has 50% of the female population mature at 60 cm; 2% and 98% of the females are assumed to be mature at about 50 and 70 cm respectively. This is based on an approximation from D'yakov's (1982) study.

4.3.2. Parameters estimated conditionally

The key parameters estimated within the model include:

- Annual recruitment estimates from 1960-1998 (1965-1969 aggregated to have a single mean value),
- Selectivity parameters for the 2 fisheries, and 3 surveys,
- Growth parameters: 5 parameters (2 for each sex, one in common),
- Parameter that scales the expected value of recruitment, and
- Effective effort-fishing mortality rates for trawl and longline fisheries (solved by matching predicted catch biomass to the observed catch biomass exactly), 1960-2002.

4.4. Model evaluation

Size composition data are not available until 1977 hence we are unable to resolve recruitment strength information during the early period (1960s) with the model. Initially, we set the individual recruitment estimates from 1960-69 equal to that predicted by an equilibrium stock-recruitment relationship. This yielded a poor fit to the size composition data (based on past assessments) and estimated a virgin recruitment level that gave the mean unfished biomass more than 1.8 million metric tons. When all recruitment deviations were estimated (the full model), a single large deviation resulted in the early part of the time series. This indicated a year class more than an order of magnitude greater than the mean estimated recruitment since 1970. Both the full model and the equilibrium recruitment models were therefore unsatisfactory. To compensate, we pooled recruitment deviation estimates from 1965-69 as in Ianelli et al. (1993).

As in past years, model configurations with the shelf survey biomass estimates treated as an absolute abundance index and the slope survey as a relative index gave unreasonable biomass levels. The best fit occurred when the slope abundance index represented only about 23% of the biomass available to the slope survey (although in previous assessments this value was about 5%). That means that a slope survey biomass estimate of 50,000 tons would expand to about 217,000 tons of actual biomass available. This value of "Q" or catchability for the slope survey is unreasonably low compared to values of Q common for other flatfish species. For this year's assessment, we selected the conservative model (where slope-survey catchability is fixed at 0.75). This fit the available data less well, but is intended to add extra conservation measures since there are a number of data inconsistencies.

Since we have a new survey estimate for Greenland turbot on the Bering Sea slope area, we focus the model on fitting this index. Previously, the index was inconsistent with the high abundance of younger Greenland turbot found in the shelf survey (in the late 1970s). However, since this survey was discontinued for a number of years, this inconsistency became less relevant to the current biomass estimated from the stock assessment model. The slope survey covers the main area of habitat for Greenland turbot; consequently, we rely on this as the primary source of abundance information. This index was given an added "emphasis" factor of 10 while for all other data sources and indices the emphasis factor was set to 1.0.

Trends in Abundance

The fits to the abundance indices are given in Fig. 4.7. The assessment model predictions for shelf survey biomass are far below the observed estimates during the early years and subsequently track the survey estimates well. These data are consistent with the conclusion of Alton et al. (1988) that recruitment of juveniles in the EBS has been low since the early 1980s. The reason that the model fits the early period of the shelf trawl survey index poorly is because such high levels of recruitment are inconsistent with observations of numbers of older fish later in the time series. The overall trend for the slope survey estimates is mimicked by the assessment model, but indicates biases based on the fixed Q values used in each model for the slope survey. The general trend of the longline survey index shows increasing numbers while the model predicts declines. The failure to fit the apparent increasing trend from the longline survey data with the model reflects the relatively large standard errors associated with this index. If we increase the model emphasis on the survey longline trend, the fits to the other surveys degrades considerably (Ianelli et al. 1995). The effect of high emphasis on the longline survey (increasing biomass trend) would indicate a much higher level of current spawning biomass.

The biomass of Greenland turbot has roughly doubled during the 1970s from the early 1960s level and is currently about half of the unfished level. The 2002 total beginning of the year biomass (age 1 and older) estimate is about 115,700 (with slope survey Q set to 0.75; Fig. 4.8). In past years, extra caution has been exercised in setting harvest levels of Greenland turbot because of the lack of recruitment success in recent years. For this reason, we selected the conservative assumption to have Q for the slope survey set equal to 0.75 for our ABC recommendations. It should be noted that the slope survey biomass estimates do not include the biomass estimates from the Aleutian Islands, which averages about one fourth to one third of the total population biomass. It is therefore still likely that the biomass estimates from this model configuration are biased towards low values. The historical fishing mortality rates (combined gears) increased over time and was highest in 1981 through 1983 (Table 4.5). A comparison of this year's model result with a similar model from the 2001 assessment (except for the added emphasis on fitting the slope survey data) is also presented in Table 4.5. The estimated historical numbers at age is given in Table 4.6.

Table 4.5. Historical fishing mortality rates (combined gear types), female spawning biomass, and beginning of year age 1+ biomass values by year and relative to the 2001 assessment.

		Female Spawner Biomass		Total Age 1+ Biomass	
Year	**F**	**2001 Asssessment**	**Current Assessment**	**2001 Assessment**	**Current Assessment**
1960	0.06	376,576	294,820	636,220	494,540
1961	0.10	360,014	278,054	609,750	468,494
1962	0.12	333,852	251,564	568,388	428,177
1963	0.07	307,656	225,101	527,496	389,004
1964	0.08	294,639	212,058	508,106	371,808
1965	0.02	281,087	198,890	494,427	359,664
1966	0.03	279,171	198,051	506,738	372,608
1967	0.06	276,226	196,918	538,387	401,401
1968	0.07	269,239	192,004	587,300	443,197
1969	0.07	261,222	185,586	651,819	496,649
1970	0.04	265,126	188,753	728,270	560,140
1971	0.07	296,360	214,766	818,110	636,175
1972	0.13	341,276	251,026	871,805	679,346
1973	0.10	380,662	279,974	866,018	667,408
1974	0.13	423,668	311,828	850,275	649,628
1975	0.13	443,667	323,166	802,467	602,233
1976	0.13	441,703	317,603	759,819	560,467
1977	0.07	417,932	295,085	717,987	519,583
1978	0.10	402,968	283,517	710,554	511,518
1979	0.11	380,534	264,370	693,598	491,966
1980	0.15	363,365	249,162	680,332	474,171
1981	0.17	342,704	228,826	656,746	444,774
1982	0.15	323,492	207,582	624,016	406,880
1983	0.14	312,400	192,250	587,991	367,897
1984	0.08	305,446	179,610	546,597	326,858
1985	0.05	310,280	178,994	520,995	305,180
1986	0.04	313,386	178,901	497,772	288,286
1987	0.04	310,352	176,229	476,375	274,537
1988	0.03	298,471	168,397	456,093	261,251
1989	0.05	282,007	158,686	439,271	250,816
1990	0.08	262,167	146,137	421,238	238,774
1991	0.08	243,318	133,056	400,042	223,514
1992	0.03	230,692	123,694	379,389	209,081
1993	0.10	227,038	122,378	368,772	204,093
1994	0.10	217,945	116,400	353,228	194,472
1995	0.09	206,376	108,638	334,453	182,215
1996	0.09	196,967	102,819	316,248	171,534
1997	0.11	190,269	98,908	298,201	161,805
1998	0.15	181,876	93,805	278,744	151,092
1999	0.09	169,750	86,238	258,040	139,131
2000	0.12	158,493	80,313	241,255	130,747
2001	0.09	145,649	73,144	224,324	121,948
2002	0.05		67,759		115,685

Table 4.6. Estimated beginning of year numbers of Greenland turbot by age and sex (millions).

Females

Yr	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21+
1973	25.54	13.37	9.02	11.97	30.56	23.60	18.60	14.64	11.46	2.32	1.78	1.39	1.09	0.87	0.69	0.52	0.41	0.33	0.28	0.23	1.14
1974	35.55	21.26	11.12	7.40	9.33	23.17	17.79	14.01	11.02	8.63	1.75	1.34	1.05	0.82	0.65	0.52	0.39	0.31	0.25	0.21	1.03
1975	16.75	29.55	17.66	9.07	5.65	6.88	16.96	13.01	10.24	8.06	6.31	1.28	0.98	0.77	0.60	0.48	0.38	0.29	0.23	0.18	0.91
1976	30.53	13.92	24.56	14.42	6.97	4.20	5.07	12.49	9.58	7.54	5.93	4.64	0.94	0.72	0.56	0.44	0.35	0.28	0.21	0.17	0.80
1977	27.41	25.38	11.57	20.05	11.07	5.17	3.09	3.73	9.19	7.04	5.55	4.36	3.41	0.69	0.53	0.41	0.33	0.26	0.21	0.16	0.71
1978	30.77	22.84	21.15	9.55	16.06	8.71	4.05	2.42	2.93	7.20	5.52	4.34	3.42	2.67	0.54	0.42	0.32	0.26	0.20	0.16	0.68
1979	24.34	25.62	19.01	17.39	7.53	12.36	6.68	3.10	1.85	2.23	5.48	4.19	3.30	2.59	2.02	0.41	0.31	0.25	0.19	0.15	0.63
1980	13.60	20.27	21.32	15.63	13.70	5.79	9.46	5.10	2.37	1.41	1.70	4.16	3.17	2.49	1.95	1.52	0.31	0.24	0.18	0.14	0.59
1981	8.76	11.32	16.85	17.44	12.07	10.25	4.30	7.02	3.78	1.75	1.04	1.25	3.05	2.32	1.81	1.42	1.11	0.22	0.17	0.13	0.53
1982	4.64	7.28	9.40	13.73	13.29	8.86	7.47	3.13	5.09	2.73	1.26	0.75	0.89	2.17	1.65	1.29	1.01	0.79	0.16	0.12	0.47
1983	3.35	3.86	6.05	7.65	10.41	9.69	6.42	5.40	2.26	3.68	1.98	0.91	0.54	0.65	1.57	1.19	0.93	0.73	0.57	0.11	0.43
1984	5.04	2.78	3.20	4.92	5.80	7.60	7.02	4.64	3.90	1.63	2.66	1.43	0.66	0.39	0.47	1.14	0.86	0.67	0.53	0.41	0.39
1985	9.21	4.20	2.32	2.64	3.91	4.51	5.88	5.43	3.59	3.02	1.27	2.06	1.10	0.51	0.30	0.36	0.88	0.67	0.52	0.41	0.62
1986	12.15	7.68	3.50	1.92	2.13	3.11	3.58	4.67	4.31	2.85	2.39	1.00	1.63	0.88	0.40	0.24	0.29	0.70	0.53	0.41	0.81
1987	8.07	10.14	6.40	2.90	1.56	1.72	2.50	2.88	3.76	3.47	2.29	1.93	0.81	1.31	0.71	0.33	0.19	0.23	0.56	0.43	0.99
1988	5.60	6.73	8.46	5.31	2.36	1.26	1.38	2.01	2.32	3.02	2.79	1.84	1.55	0.65	1.06	0.57	0.26	0.16	0.19	0.45	1.14
1989	5.11	4.67	5.61	7.03	4.35	1.92	1.02	1.12	1.63	1.88	2.45	2.26	1.49	1.26	0.53	0.86	0.46	0.21	0.13	0.15	1.29
1990	6.62	4.27	3.90	4.69	5.87	3.63	1.59	0.83	0.90	1.31	1.50	1.96	1.80	1.19	1.00	0.42	0.68	0.37	0.17	0.10	1.14
1991	8.82	5.53	3.56	3.26	3.91	4.89	2.99	1.28	0.66	0.71	1.02	1.17	1.52	1.40	0.92	0.78	0.33	0.53	0.28	0.13	0.96
1992	3.91	7.36	4.62	2.98	2.72	3.26	4.03	2.40	1.01	0.51	0.55	0.79	0.90	1.17	1.08	0.71	0.60	0.25	0.41	0.22	0.84
1993	3.12	3.27	6.15	3.86	2.49	2.27	2.72	3.33	1.98	0.83	0.42	0.45	0.64	0.74	0.96	0.88	0.58	0.49	0.20	0.33	0.86
1994	2.84	2.61	2.73	5.14	3.22	2.07	1.89	2.25	2.74	1.61	0.67	0.34	0.35	0.51	0.57	0.74	0.68	0.44	0.37	0.16	0.91
1995	2.83	2.37	2.18	2.28	4.29	2.69	1.72	1.54	1.81	2.18	1.27	0.52	0.26	0.27	0.39	0.44	0.57	0.52	0.34	0.28	0.81
1996	3.94	2.36	1.98	1.82	1.90	3.58	2.23	1.41	1.25	1.45	1.74	1.00	0.41	0.20	0.21	0.30	0.34	0.44	0.40	0.26	0.84
1997	3.63	3.29	1.97	1.66	1.52	1.59	2.98	1.84	1.16	1.02	1.17	1.39	0.80	0.32	0.16	0.17	0.23	0.26	0.34	0.31	0.84
1998	3.68	3.03	2.75	1.65	1.38	1.27	1.32	2.47	1.51	0.94	0.82	0.93	1.09	0.62	0.25	0.12	0.13	0.18	0.20	0.25	0.87
1999	3.51	3.08	2.53	2.30	1.38	1.15	1.05	1.09	2.01	1.22	0.74	0.64	0.71	0.83	0.47	0.19	0.09	0.09	0.13	0.15	0.82
2000	4.81	2.93	2.57	2.11	1.92	1.15	0.96	0.87	0.89	1.63	0.98	0.59	0.50	0.56	0.65	0.36	0.14	0.07	0.07	0.10	0.74
2001	4.81	4.02	2.45	2.15	1.77	1.60	0.95	0.79	0.71	0.72	1.30	0.77	0.46	0.39	0.43	0.49	0.27	0.11	0.05	0.05	0.63
2002	4.81	4.02	3.36	2.04	1.79	1.47	1.33	0.79	0.64	0.57	0.58	1.03	0.61	0.36	0.30	0.33	0.38	0.21	0.08	0.04	0.52

Males

Yr	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21+
1973	25.54	13.37	9.02	11.99	30.91	23.91	18.80	14.80	11.59	2.34	1.80	1.40	1.11	0.88	0.70	0.54	0.42	0.34	0.28	0.24	1.20
1974	35.55	21.26	11.12	7.41	9.43	23.57	18.07	14.17	11.15	8.73	1.77	1.36	1.06	0.83	0.66	0.53	0.41	0.32	0.26	0.21	1.09
1975	16.75	29.55	17.66	9.09	5.72	7.00	17.30	13.22	10.36	8.15	6.38	1.29	0.99	0.77	0.61	0.49	0.39	0.30	0.23	0.19	0.96
1976	30.53	13.92	24.55	14.45	7.05	4.28	5.18	12.75	9.74	7.63	6.00	4.70	0.95	0.73	0.57	0.45	0.36	0.29	0.22	0.17	0.85
1977	27.41	25.38	11.57	20.09	11.20	5.27	3.16	3.81	9.38	7.16	5.61	4.42	3.46	0.70	0.54	0.42	0.33	0.27	0.21	0.16	0.76
1978	30.77	22.84	21.15	9.57	16.17	8.85	4.14	2.48	2.99	7.35	5.62	4.40	3.46	2.72	0.55	0.42	0.33	0.26	0.21	0.17	0.73
1979	24.34	25.62	19.01	17.42	7.59	12.51	6.79	3.17	1.90	2.29	5.62	4.29	3.36	2.65	2.08	0.42	0.32	0.25	0.20	0.16	0.69
1980	13.60	20.27	21.32	15.65	13.81	5.87	9.59	5.20	2.42	1.45	1.75	4.29	3.28	2.57	2.02	1.59	0.32	0.25	0.19	0.15	0.65
1981	8.76	11.32	16.85	17.47	12.20	10.40	4.37	7.12	3.86	1.80	1.07	1.29	3.18	2.43	1.90	1.50	1.18	0.24	0.18	0.14	0.60
1982	4.64	7.28	9.40	13.76	13.46	9.03	7.60	3.18	5.18	2.80	1.31	0.78	0.94	2.31	1.76	1.38	1.09	0.85	0.17	0.13	0.54
1983	3.35	3.86	6.05	7.67	10.56	9.90	6.55	5.50	2.30	3.75	2.03	0.94	0.56	0.68	1.67	1.28	1.00	0.79	0.62	0.13	0.49
1984	5.04	2.78	3.20	4.93	5.88	7.77	7.19	4.74	3.98	1.66	2.71	1.47	0.68	0.41	0.49	1.21	0.93	0.73	0.58	0.45	0.45
1985	9.21	4.20	2.32	2.64	3.94	4.60	6.02	5.56	3.67	3.08	1.29	2.10	1.14	0.53	0.32	0.38	0.94	0.72	0.57	0.45	0.70
1986	12.15	7.68	3.50	1.92	2.14	3.15	3.65	4.78	4.41	2.91	2.44	1.02	1.66	0.90	0.42	0.25	0.30	0.75	0.57	0.45	0.92
1987	8.07	10.14	6.40	2.91	1.57	1.73	2.54	2.94	3.85	3.55	2.34	1.97	0.82	1.34	0.73	0.34	0.20	0.25	0.61	0.46	1.10
1988	5.60	6.73	8.46	5.31	2.37	1.27	1.39	2.04	2.36	3.09	2.86	1.89	1.58	0.66	1.08	0.58	0.27	0.16	0.20	0.49	1.26
1989	5.11	4.67	5.61	7.03	4.37	1.93	1.03	1.13	1.66	1.92	2.51	2.32	1.53	1.28	0.54	0.88	0.47	0.22	0.13	0.16	1.42
1990	6.62	4.27	3.90	4.69	5.87	3.64	1.61	0.85	0.93	1.35	1.55	2.02	1.86	1.23	1.03	0.43	0.70	0.38	0.18	0.11	1.27
1991	8.82	5.53	3.56	3.26	3.91	4.90	3.03	1.33	0.69	0.74	1.07	1.22	1.59	1.46	0.96	0.81	0.34	0.55	0.30	0.14	1.08
1992	3.91	7.36	4.62	2.98	2.72	3.27	4.08	2.49	1.07	0.55	0.59	0.84	0.96	1.24	1.14	0.75	0.63	0.26	0.43	0.23	0.95
1993	3.12	3.27	6.15	3.86	2.49	2.27	2.73	3.39	2.07	0.89	0.45	0.48	0.69	0.78	1.02	0.93	0.61	0.51	0.22	0.35	0.97
1994	2.84	2.61	2.73	5.14	3.22	2.08	1.90	2.27	2.82	1.71	0.73	0.37	0.40	0.56	0.64	0.83	0.76	0.50	0.42	0.17	1.06
1995	2.83	2.37	2.18	2.28	4.29	2.69	1.73	1.57	1.86	2.28	1.38	0.58	0.30	0.31	0.45	0.51	0.65	0.60	0.39	0.33	0.97
1996	3.94	2.36	1.98	1.82	1.90	3.58	2.24	1.43	1.29	1.52	1.86	1.11	0.47	0.24	0.25	0.36	0.41	0.52	0.48	0.31	1.03
1997	3.63	3.29	1.97	1.66	1.52	1.59	2.99	1.87	1.19	1.07	1.25	1.52	0.91	0.38	0.19	0.20	0.29	0.33	0.42	0.39	1.09
1998	3.68	3.03	2.75	1.65	1.38	1.27	1.33	2.49	1.55	0.98	0.88	1.02	1.24	0.74	0.31	0.16	0.17	0.23	0.26	0.34	1.18
1999	3.51	3.08	2.53	2.30	1.38	1.15	1.06	1.10	2.06	1.27	0.80	0.71	0.83	1.00	0.60	0.25	0.13	0.13	0.19	0.21	1.20
2000	4.81	2.93	2.57	2.11	1.92	1.15	0.96	0.88	0.91	1.69	1.04	0.66	0.58	0.67	0.81	0.48	0.20	0.10	0.11	0.15	1.13
2001	4.81	4.02	2.45	2.15	1.77	1.60	0.96	0.80	0.73	0.75	1.38	0.85	0.53	0.47	0.54	0.65	0.39	0.16	0.08	0.08	1.01
2002	4.81	4.02	3.36	2.04	1.79	1.47	1.34	0.80	0.66	0.60	0.61	1.13	0.69	0.43	0.38	0.44	0.52	0.31	0.13	0.07	0.88

Selectivity

Selectivity of Greenland turbot varied considerably between all of the surveys and fisheries. The shelf survey selected only small fish whereas the slope survey caught much larger fish. A similar pattern was observed between the trawl and longline fisheries with the longline fishery consistently catching larger

Greenland turbot (Fig. 4.9). Note that the average selectivity estimates for the slope and shelf surveys indicate that our surveys do not sample intermediate size fish (35-50cm) very well. The reason for this is not clear; however, we feel that it is related to the apparent bi-modality in the size distribution observed in the trawl fishery.

Fit to Size Composition Data

Size composition observations from the fisheries and surveys are generally poorly matched by the model predictions. In some years, relatively few fish were measured so adjustments of the model to those data would depend on the trade-off in fitting other data, which may have had more extensive sampling. Second, unaccounted fish movement and hence changing availability affects fits to size composition data when an "average" gear selectivity is used. Finally, natural mortality rate is undoubtedly variable among cohorts and years, the extent of which would affect our ability to model the age structure of the population accurately. The nature of the inconsistencies among data types is presented below, particularly as they pertain to assessing the current stock status.

Recruitment

Recruitment of young juvenile Greenland turbot has been poor since the early 1980s based on EBS shelf trawl surveys. There were several strong year-classes through the 1970s, which were followed by poor recruitment of Greenland turbot since the early 1980s (Fig. 4.10). Preliminary analyses on fitting the stock-recruitment relationship indicated that the residuals were highly auto-correlated. For the present analyses, the authors feel that model assumptions are too great to pursue stock-recruitment analyses. Progress was made in the past year towards developing alternative model for Greenland turbot. This new approach may prove useful for providing reasonable estimates of F_{msy} (and associated uncertainty) that may be useful in considerations for Tier 1 of Amendment 56.

4.5. Projections and harvest alternatives

Maximum Sustainable Yield

Maximum sustainable yield (MSY) calculations require assumptions about the stock recruitment relationship, which for Greenland turbot may be impractical as many functional forms can fit the data equally well. As presented above, the harvest strategy relative to reductions in spawning biomass per recruit (e.g., $F_{40\%}$) was selected in the absence of information on the stock-recruitment productivity relationship required for calculating MSY levels.

ABC and Overfishing levels

The recommended harvest levels vary considerably among models depending on the assumptions made about the catchability coefficients from the slope-trawl survey (Ianelli et al. 1999). Since there are several areas of uncertainty surrounding this assessment, for the basis for recommendations we selected a conservative configuration (assuming slope-survey catchability=0.75). The status of the projected spawning biomass in year 2003 relative to $B_{40\%}$ would place Greenland turbot in Tier 3a of Amendment 56.

We computed $B_{40\%}$ value by using the mean recruitment estimated for the period 1978-1998. The results indicate that the long-term average female spawning biomass is around 54,400 tons. The current estimate of the year 2003 female spawning biomass is about 67,800 t.

While the Council and past recommendations have intentionally been extra conservative with the idea of promoting the recovery of Greenland turbot in the EBS and Aleutian Islands region, the stock appears to be on a continuing decline. While the stock is technically not overfished and is currently above $B_{40\%}$, we feel that extra caution is warranted. The new survey information from the slope region provides insight on the abundance of Greenland turbot in their main habitat area (the most recent survey prior to that of 2002 was in 1991). However, we feel that an ABC based on the recent 5-year average fishing mortality is recommended which is **5,880 tons.** We feel that this is justified since in the projections we anticipate further declines given the current estimate of the age composition of the stock.

Our recommendation for overfishing, based on the adjusted $F_{35\%}$ rate is **17,800 t** corresponding to a full-selection F of 0.32. The value of the Council's overfishing definition depends on the age-specific selectivity of the fishing gear, the somatic growth rate, natural mortality, and the size (or age) -specific maturation rate. As this rate depends on assumed selectivity, future yields are sensitive to relative gear-specific harvest levels. Because harvest of this resource is not allocated by gear type, the unpredictable nature of future harvests between gears is an added source of uncertainty. However, this uncertainty is considerably less than uncertainty related to treatment of survey biomass levels, i.e., factors which contribute to estimating absolute biomass (Ianelli et al. 1999).

4.5.1. Standard harvest scenarios and projections

This year, a standard set of projections is required for each stock managed under Tiers 1, 2, or 3 of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Protection Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

For each scenario, the projections begin with the vector of 2002 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2003 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2002 (here assumed to be 2,700 t). In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2003, are as follow ("*max* F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

Scenario 1: In all future years, F is set equal to *max* F_{ABC}. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)

Scenario 2: In all future years, F is set equal to a constant fraction of *max* F_{ABC}, where this fraction is equal to the ratio of the F_{ABC} value for 2002 recommended in the assessment to the *max* F_{ABC} for 2002. (Rationale: When F_{ABC} is set at a value below *max* F_{ABC}, it is often set at the value recommended in the stock assessment.)

Scenario 3: In all future years, F is set equal to 50% of max F_{ABC}. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)

Scenario 4: In all future years, F is set equal to the 1997-2001 average F. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)

Scenario 5: In all future years, F is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

Scenarios 1 through 5 were projected 13 years from 2002 (Table 4.7).

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether a stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follows (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$):

Scenario 6: In all future years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be above ½ of its MSY level in 2003 and above its MSY level in 2013 under this scenario, then the stock is not overfished.)

Scenario 7: In 2003 and 2004, F is set equal to *max* F_{ABC}, and in all subsequent years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is expected to be above its MSY level in 2015 under this scenario, then the stock is not approaching an overfished condition.)

Our projection model run under these conditions indicates that for Scenario 6, the Greenland turbot stock is not overfished based on the first criterion (year 2003 spawning biomass estimated at 64,900 t relative to ½ $B_{35\%}$ = 23,800 tons). Under the guidelines, since the year 2003 biomass estimate is well above the $B_{35\%}$ level (and $B_{40\%}$) we have determined that the stock is not overfished.

Projections of fishable biomass 13 years into the future under alternative fishing mortality rates were examined. The same natural mortality and growth parameters that were used in the previous stock synthesis runs were employed for the projections. The results suggest a continued decline until about 2007 (Fig. 4.11). For this scenario, annual yield drops as low as 8,700 t and biomass falls to about 67% of the $B_{40\%}$ level. Under Scenarios 6 and 7, `the projected spawning biomass for Greenland turbot is not currently overfished, nor is it approaching an overfished status.

Table 4.7. Mean spawning biomass, F, and yield projections for Greenland turbot, 2002-2015. The full-selection fishing mortality rates (*F's*) between longline and trawl gears were assumed **equal**. The values for $B_{40\%}$ and $B_{35\%}$ are 54,400 and 47,600 tons, respectively.

Sp.Biomass	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**	**Scenario 7**
2002	67,762	67,762	67,762	67,762	67,762	67,762	67,762
2003	64,936	64,936	64,936	64,936	64,936	64,936	64,936
2004	53,468	60,084	58,714	60,084	64,536	51,148	53,468
2005	45,365	56,239	53,844	56,239	64,426	42,260	45,365
2006	41,085	53,572	50,481	53,572	64,847	37,904	39,713
2007	39,138	52,019	48,712	52,019	65,816	36,079	37,156
2008	38,916	51,697	48,397	51,697	67,580	36,006	36,637
2009	40,444	53,053	49,805	53,053	70,720	37,642	37,994
2010	43,208	55,943	52,632	55,943	75,260	40,420	40,599
2011	46,256	59,660	56,120	59,660	80,640	43,347	43,425
2012	48,962	63,536	59,645	63,536	86,197	45,808	45,831
2013	51,147	67,273	62,946	67,273	91,711	47,658	47,656
2014	52,773	70,656	65,841	70,656	96,962	48,921	48,910
2015	53,932	73,624	68,303	73,624	101,857	49,728	49,716
Fishing Mort	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
2002	0.04	0.04	0.04	0.04	0.04	0.04	0.04
2003	0.26	0.10	0.13	0.10	0.00	0.32	0.26
2004	0.26	0.10	0.13	0.10	0.00	0.30	0.26
2005	0.22	0.10	0.13	0.10	0.00	0.25	0.27
2006	0.19	0.10	0.12	0.10	0.00	0.22	0.23
2007	0.18	0.10	0.12	0.10	0.00	0.21	0.22
2008	0.18	0.10	0.12	0.10	0.00	0.21	0.21
2009	0.19	0.10	0.12	0.10	0.00	0.22	0.22
2010	0.20	0.10	0.12	0.10	0.00	0.24	0.24
2011	0.22	0.10	0.12	0.10	0.00	0.25	0.25
2012	0.23	0.10	0.13	0.10	0.00	0.26	0.26
2013	0.23	0.10	0.13	0.10	0.00	0.27	0.27
2014	0.24	0.10	0.13	0.10	0.00	0.28	0.28
2015	0.24	0.10	0.13	0.10	0.00	0.28	0.28
Yield	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
2002	2,700	2,700	2,700	2,700	2,700	2,700	2,700
2003	14,718	5,879	7,700	5,879	0	17,848	14,718
2004	11,994	5,435	6,963	5,435	0	13,386	11,994
2005	8,697	5,076	6,318	5,076	0	9,243	10,592
2006	7,126	4,820	5,534	4,820	0	7,433	8,144
2007	6,421	4,653	5,120	4,653	0	6,683	7,088
2008	6,306	4,598	5,025	4,598	0	6,610	6,850
2009	6,794	4,687	5,272	4,687	0	7,211	7,353
2010	7,693	4,894	5,695	4,894	0	8,272	8,351
2011	8,664	5,170	6,148	5,170	0	9,406	9,444
2012	9,504	5,472	6,580	5,472	0	10,366	10,380
2013	10,173	5,778	6,984	5,778	0	11,090	11,092
2014	10,685	6,068	7,343	6,068	0	11,614	11,612
2015	11,060	6,332	7,658	6,332	0	11,953	11,950

4.6. Other Considerations

4.6.1. Subarea Allocation

In this assessment, we have adopted the hypothesis proposed by Alton et al. (1989) regarding the stock structure of Greenland turbot in the eastern Bering Sea and Aleutian Islands regions. Briefly, spawning is thought to occur throughout the adult range with post-larval settlement occurring on the shelf in shallow areas. The young fish on the shelf begin to migrate to the slope region at about age 4 or 5. In our treatment, the spawning stock includes adults in the Aleutian Islands and the eastern Bering Sea. In support of this hypothesis, we examined the length compositions from the Aleutian Islands surveys and found a lack of small Greenland turbot, which suggests that these fish migrate from other areas (Ianelli et al. 1993). Historically, the catches between the Aleutian Islands and eastern Bering Sea has varied (Table 4.8).

Table 4.8. Estimated total Greenland turbot harvest by area, 1977-2001.

Year	EBS	Aleutians	Year	EBS	Aleutians
1977	27,708	2,453	1991	4,075	3,636
1978	37,423	4,766	1992	951	725
1979	34,998	6,411	1993	5,125	3,323
1980	48,856	3,697	1994	6,902	3,032
1981	52,921	4,400	1995	5,713	2,086
1982	45,805	6,317	1996	4,386	1,578
1983	43,443	4,115	1997	6,594	943
1984	21,317	1,803	1998	8,303	821
1985	14,698	33	1999	5,204	423
1986	7,710	2,154	2000	5,624	1,017
1987	6,519	3,066	2001	4,197	1,046
1988	6,064	1,044			
1989	4,061	4,761			
1990	7,702	2,494			

Since we acknowledge having limited information on the movement and recruitment processes for this species and in the interest of harvesting the "stock" evenly, we recommend that the ABC be split between regions. Based on eastern Bering Sea slope survey estimates and Aleutian Islands surveys, the proportion of the adult biomass in the Aleutian Islands region has ranged from 24% to 49%. We therefore recommend the ABC for the Aleutian Islands be set 33% of the total ABC, with 67% allocated to the eastern Bering Sea. These rates represent the mid-point of the values observed from biomass estimates and give the following allocation:

Aleutian Islands	1,960 mt
Eastern Bering Sea	3,920 mt
Total	5,880 mt

4.6.2. Ecosystem considerations

Greenland turbot have undergone dramatic declines in the abundance of immature fish on the EBS shelf region compared to observations during the late 1970's. It may be that the high level of abundance during this period was unusual and the current level is typical for Greenland turbot life history pattern. Without further information on where different life-stages are currently residing, we can only speculate on the plausibility of this scenario. Several major predators on the shelf were at relatively low stock sizes during the late 1970's (e.g., Pacific cod, Pacific halibut) and these increased to peak levels during the mid 1980's. Perhaps this shift in abundance has reduced the survival of juvenile Greenland turbot in the EBS shelf. Alternatively, the shift in recruitment patterns for Greenland turbot may be due to the documented environmental regime that occurred during the late 1970's. That is, perhaps the critical life history stages are subject to different oceanographic conditions that affect the abundance of juvenile Greenland turbot on the EBS shelf.

Currently, the ecosystem group within the REFM Division is actively evaluating the pattern of mortality between different species in the EBS. One aspect of this work involves developing a multi-species model. Results from this work indicate that Greenland turbot is an important predator.

The NMFS Auke Bay Lab staff continued to conduct a tagging study of Greenland turbot from the longline survey which they started in 1997. A Greenland turbot at large for over 16 years was recaptured on the Bering Sea slope area. This individual fish was tagged in the Sea of Okhotsk, further suggesting that Greenland turbot in the EBS/AI may not be a closed population. A figure showing this recapture and some others from recent longline survey releases is shown below in Fig. 4.12.

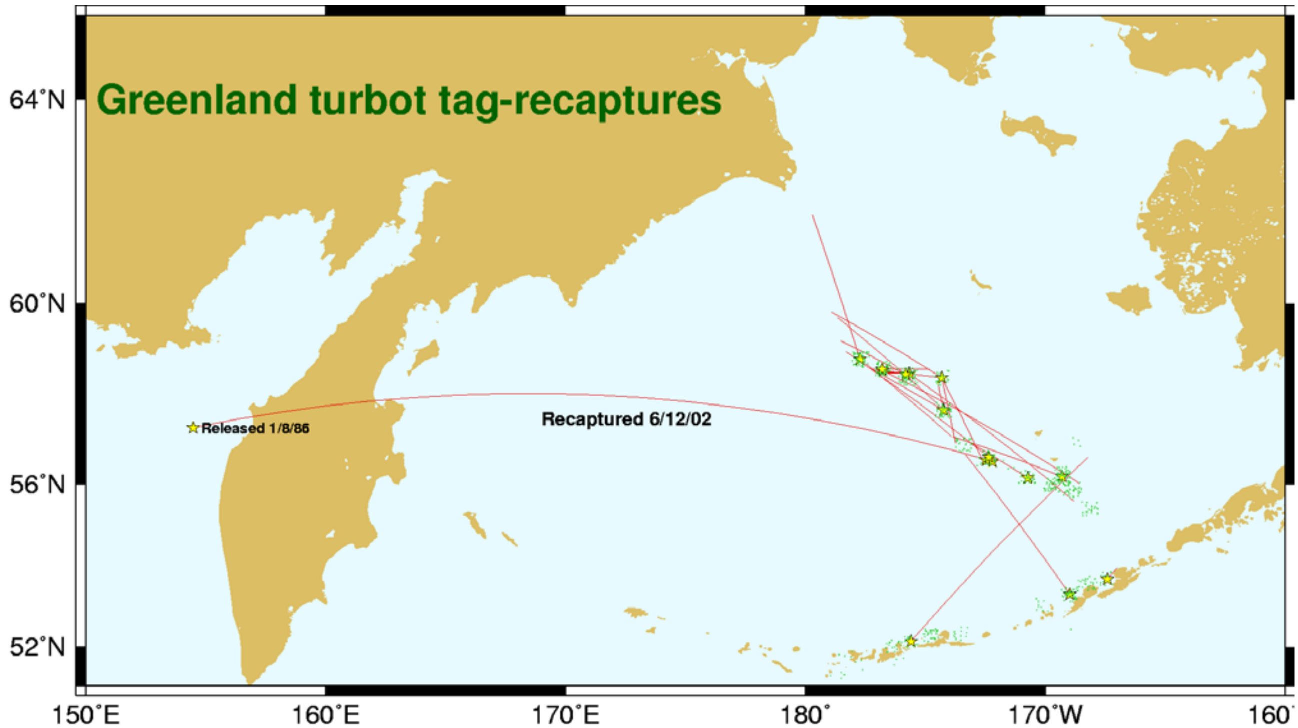

Figure 4.12. Map showing the distribution of Greenland turbot tagged (stars) and released that were recaptured (line endpoints).

4.7. Summary

The management parameters of interest derived from this assessment are presented in Table 4.9.

Table 4.9. Summary management values based on this assessment. Note that the fishing mortality rates assume 50% contribution from longline gear and 50% from trawl.

Management Parameter	Value
M	0.18 yr-1
Approximate age at full recruitment	10 years
$F_{35\%}$	0.32
$F_{40\%}$	0.26
$B_{40\%}$	54,400 t
Year 2003 female spawning biomass	64,900 t
F_{ABC} = 5-year average	0.10
Recommended ABC	**5,800**
$F_{overfishing} = F_{35\%}$	0.32
Overfishing level	**17,800 t**

4.8. Acknowledgments

Mike Sigler and Chris Lunsford provided the summaries for the 1996-2001 longline survey data.

4.9. References

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4.10. Figures

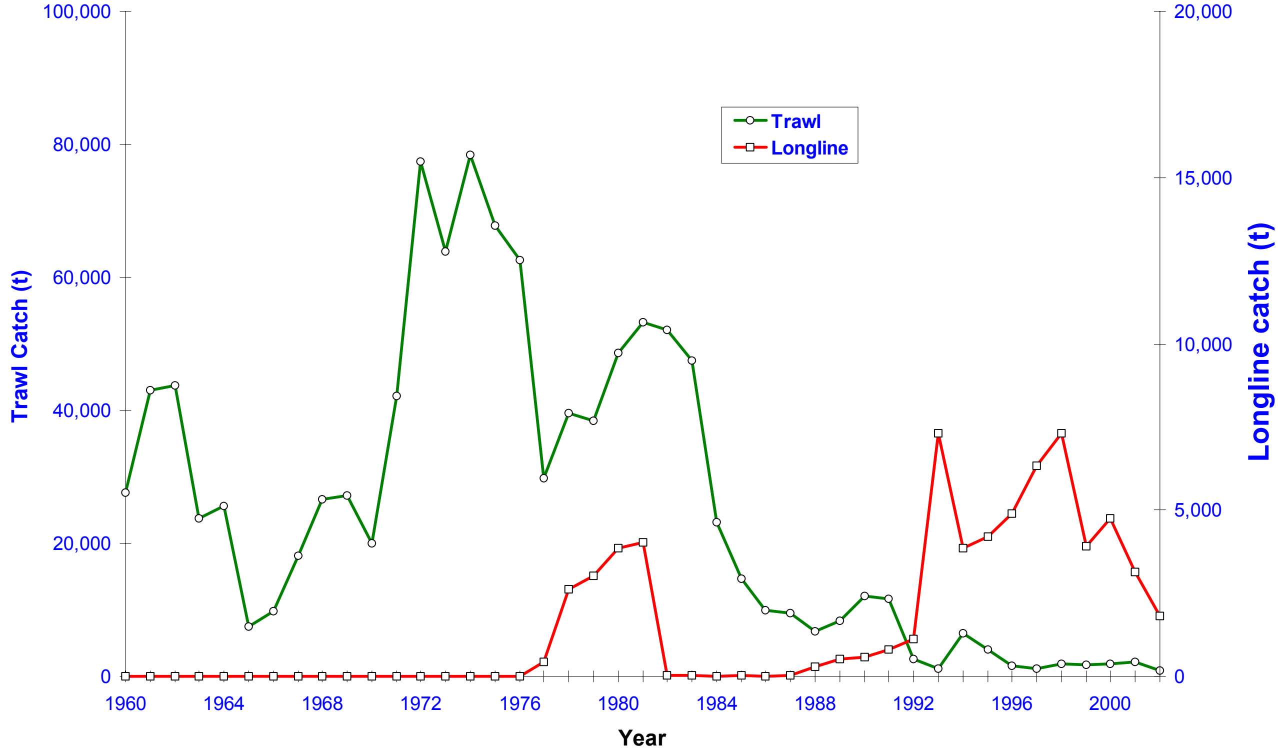

Figure 4.1. Comparison of trawl (1960-2002) and longline (1977-2002) catches of Greenland turbot in the combined EBS/AI area.

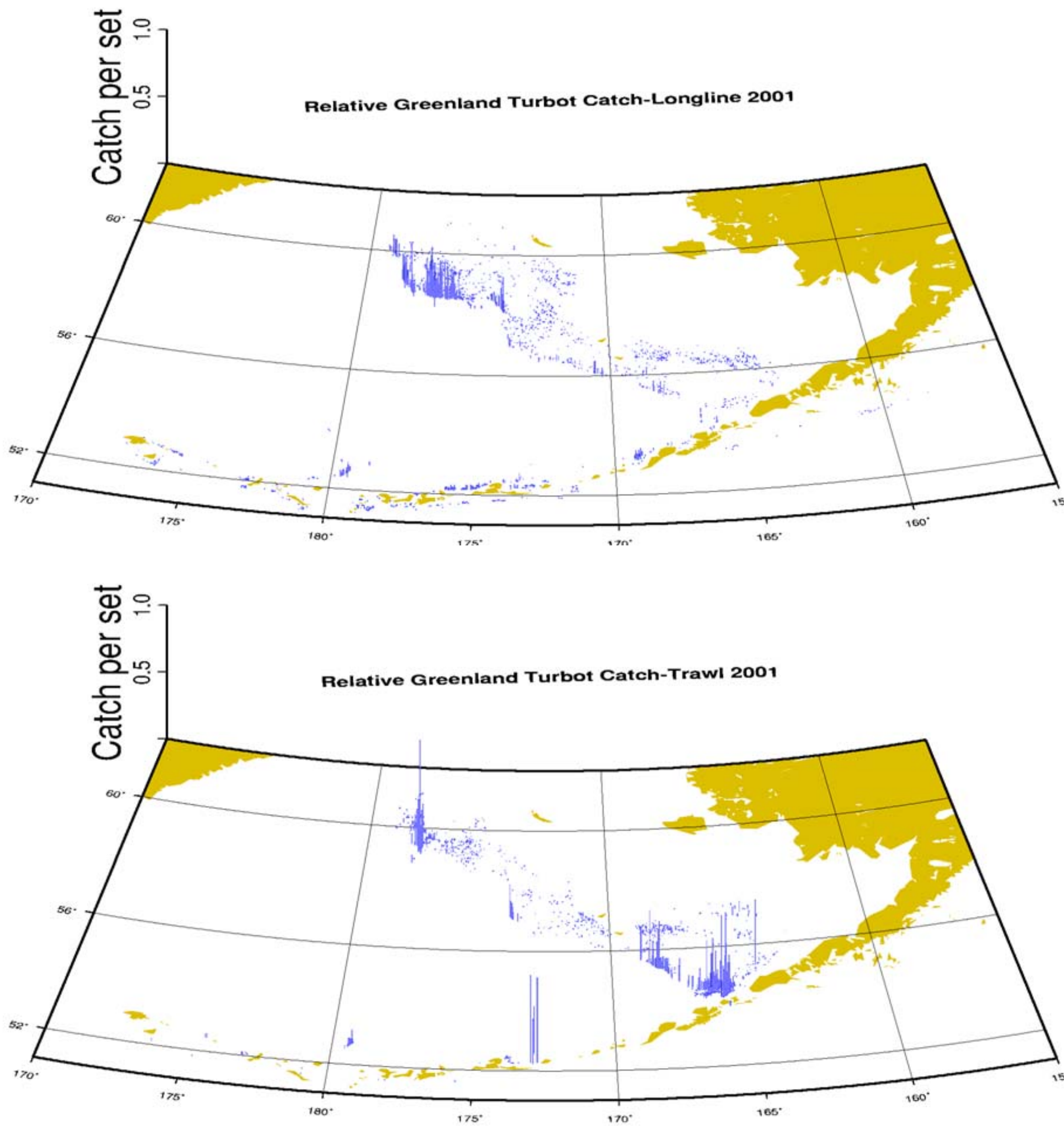

Figure 4.2. 2001 longline and trawl locations of successful Greenland turbot fishing operations based on NMFS observer data. Vertical lines represent the relative magnitude of Greenland turbot catch for each observed fishing operation.

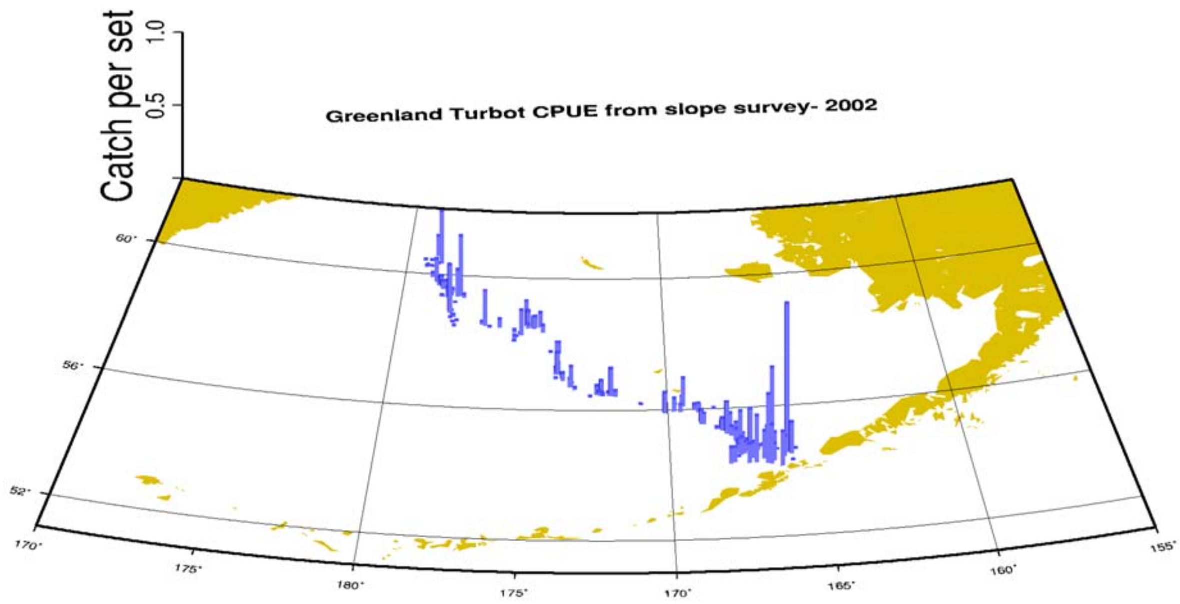

Figure 4.3. Relative CPUE from slope bottom trawl survey for 2002. Height of vertical bars is relative to CPUE by weight.

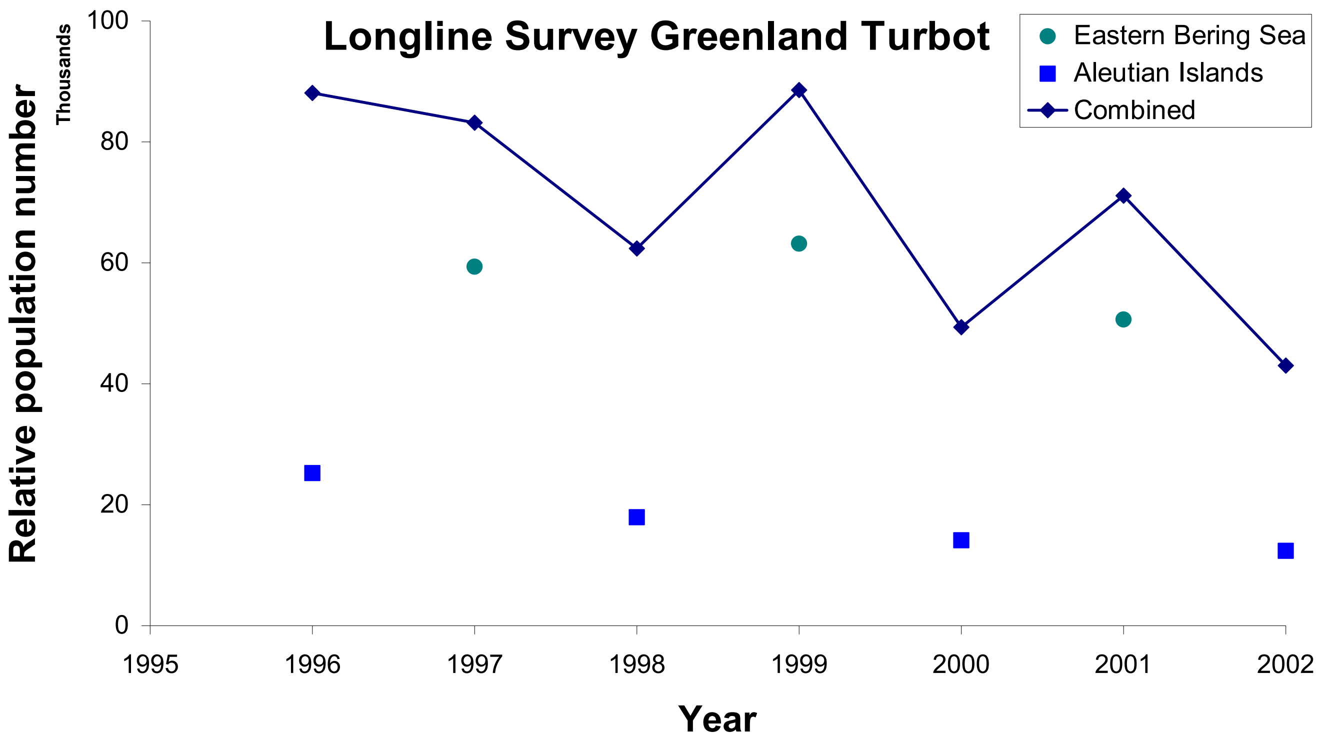

Figure 4.4. Greenland turbot longline survey abundance trends for the 2 regions and as combined and used within the assessment model.

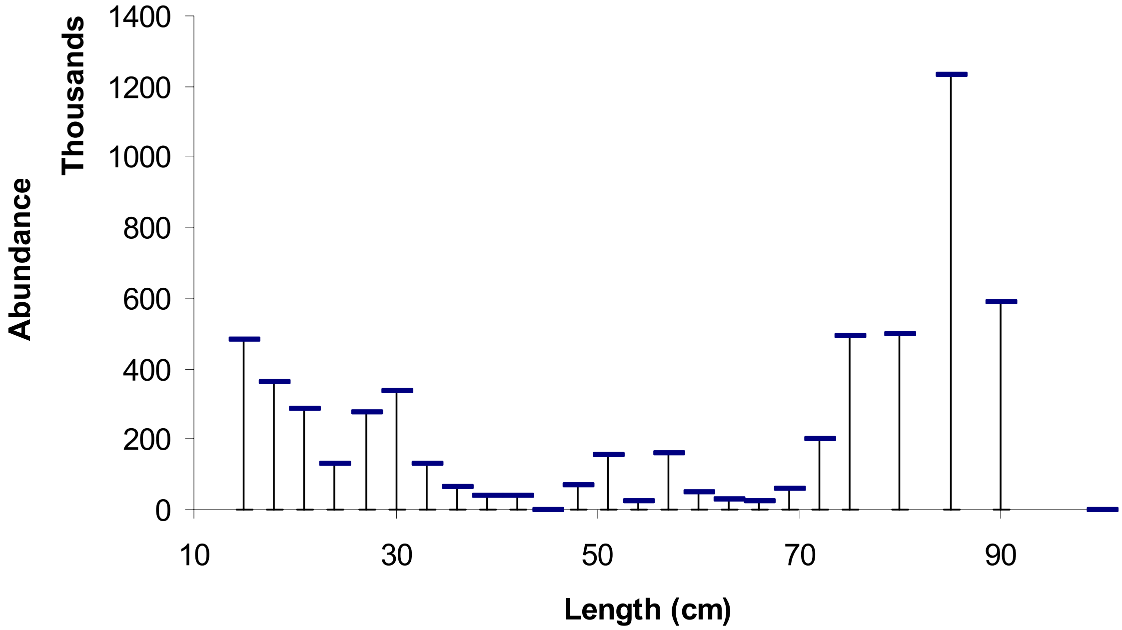

Figure 4.5. Length frequency of Greenland turbot observed from the summer 2002 NMFS bottom trawl **shelf** survey.

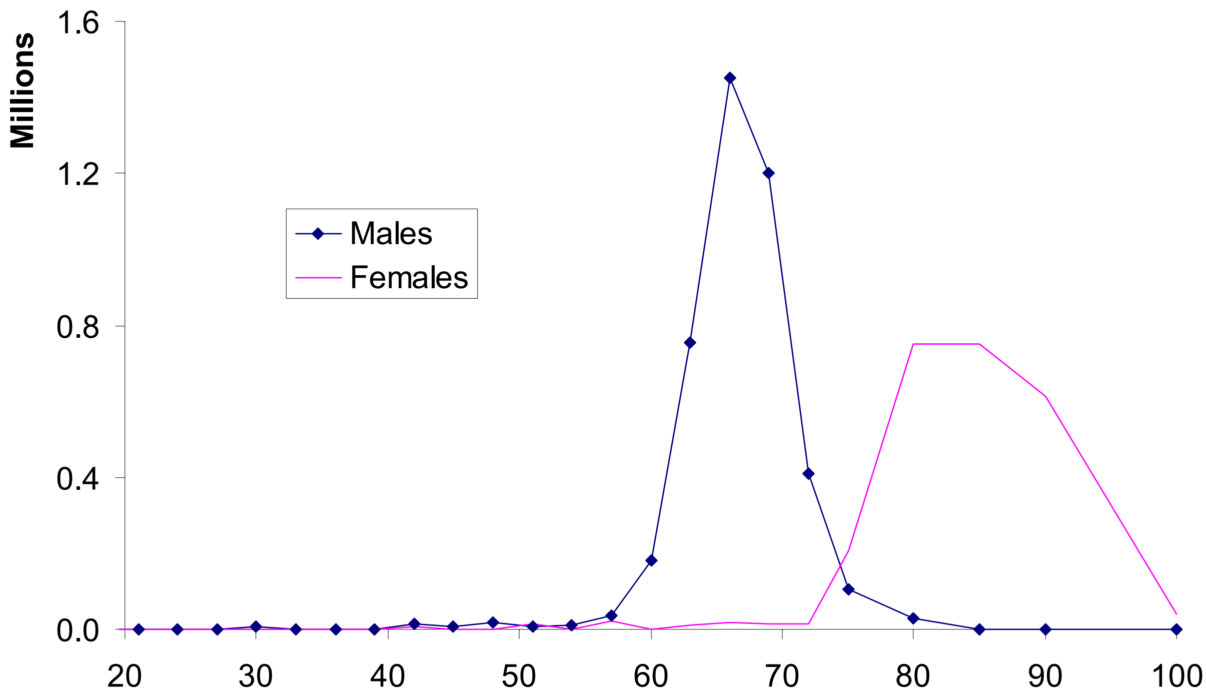

Figure 4.6. Length frequency of Greenland turbot observed from the summer 2002 NMFS bottom trawl **slope** survey.

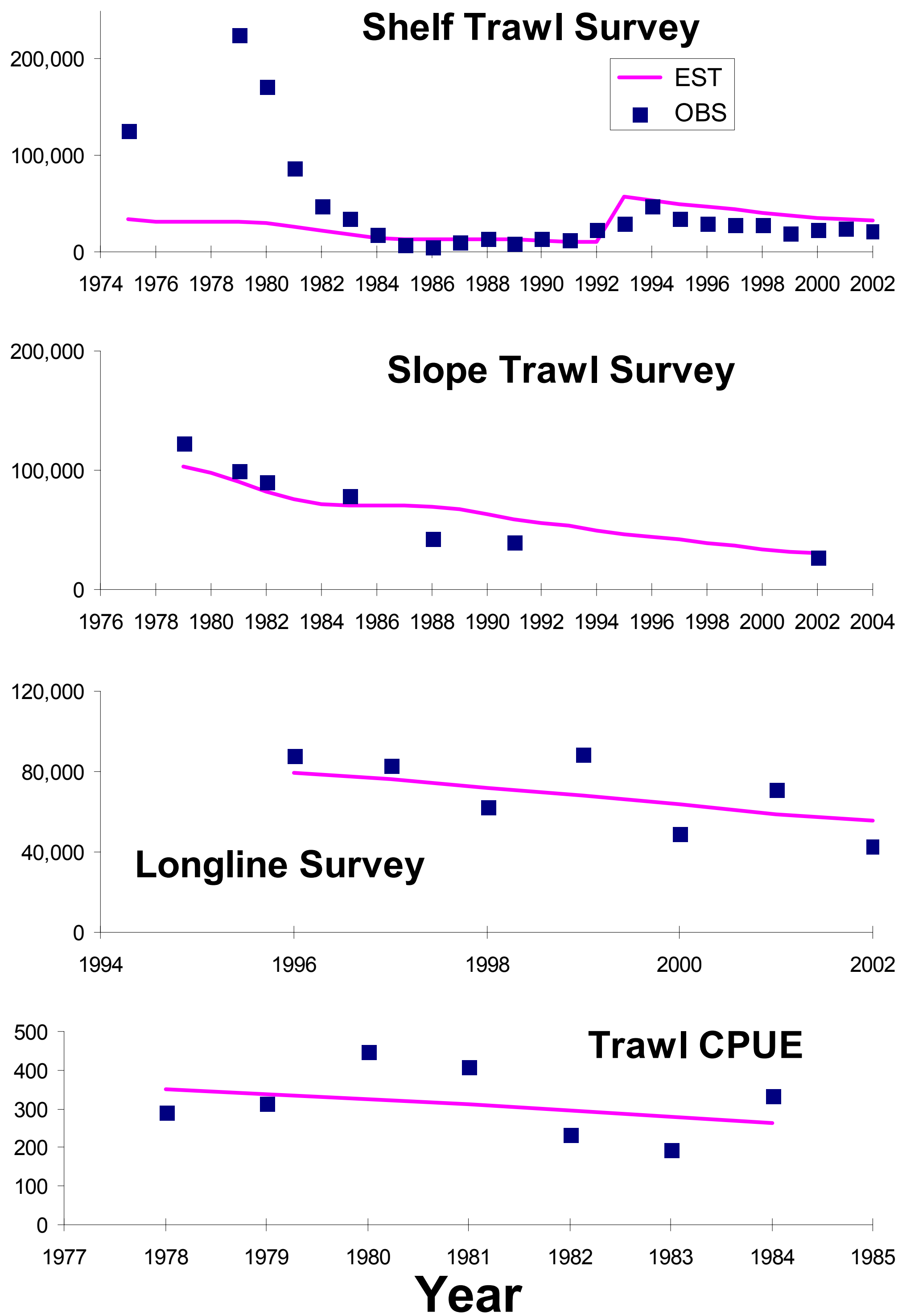

Figure 4.7. Fits to the different survey and fishery indices for Greenland turbot in the EBS/AI region.

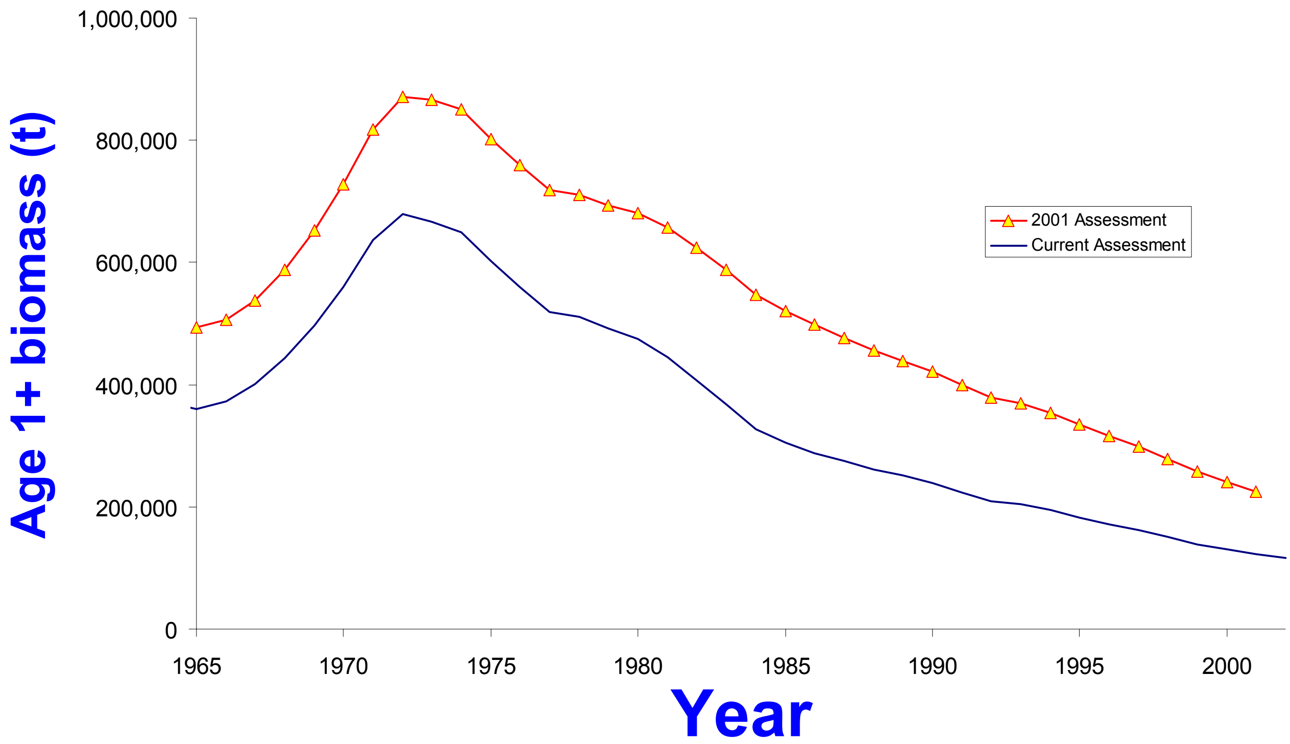

Figure 4.8 Total age 1+ biomass trend for the individual models of Greenland turbot in the EBS/AI region, 1965-2002 compared to Ianelli et al.'s (2001) assessment.

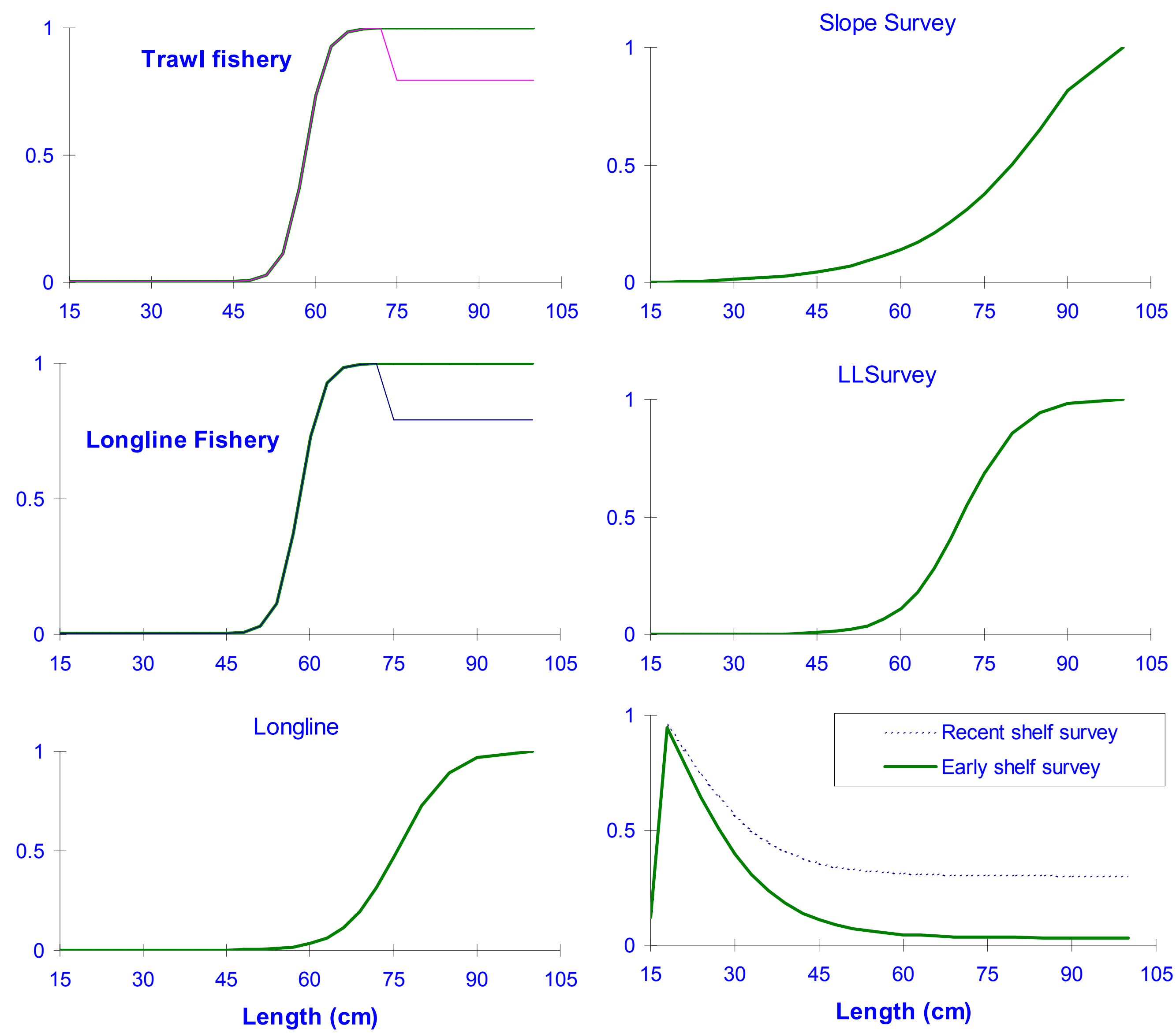

Figure 4.9. Size-specific selectivity patterns for surveys and fisheries of Greenland turbot in the EBS/AI region. Thin lines represent differential selectivity of males.

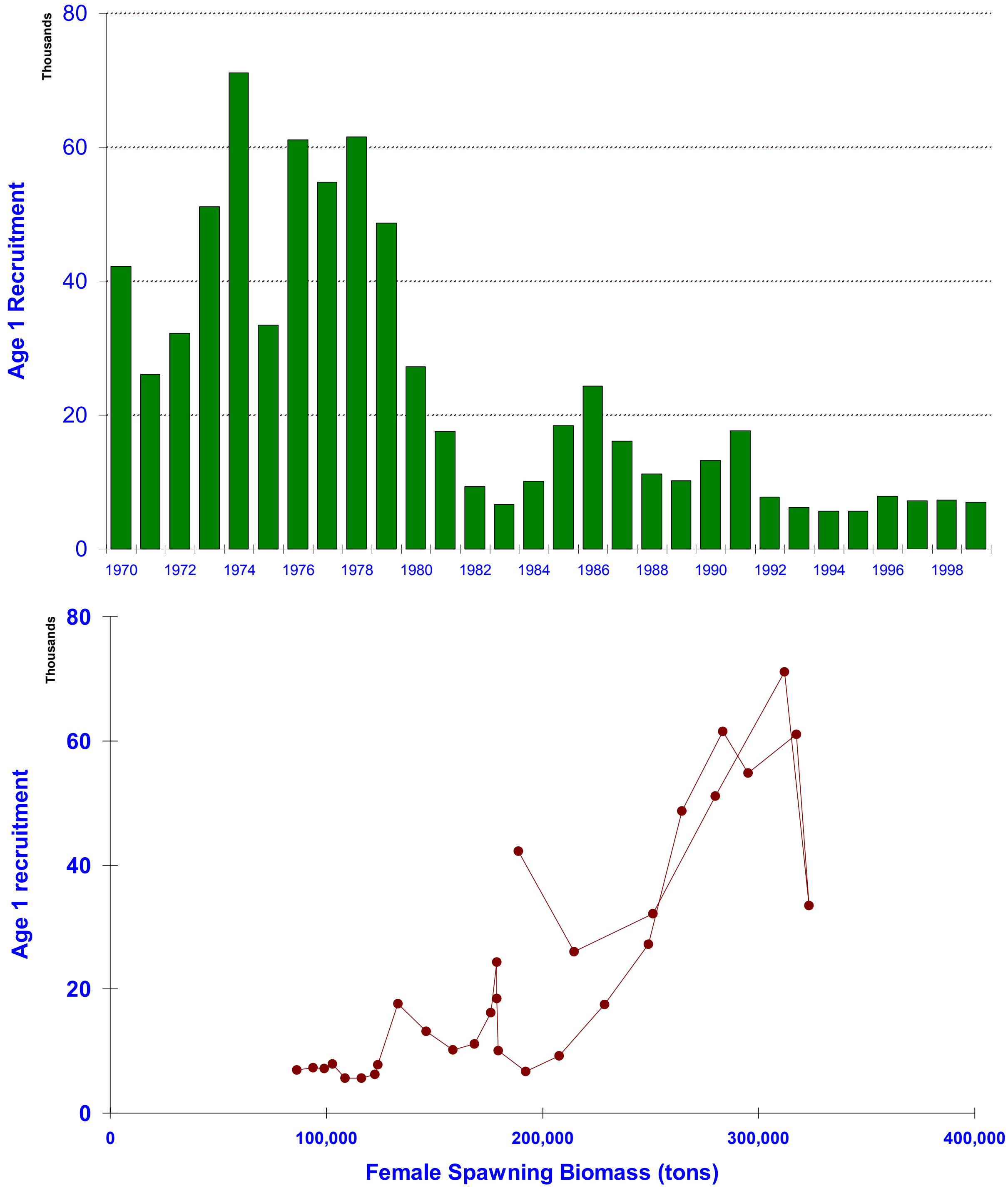

Figure 4.10. Estimated recruitment to age 1 (upper panel) and the observed stock-recruitment pattern (lower panel) of Greenland turbot in the EBS/AI region, 1970-2002.

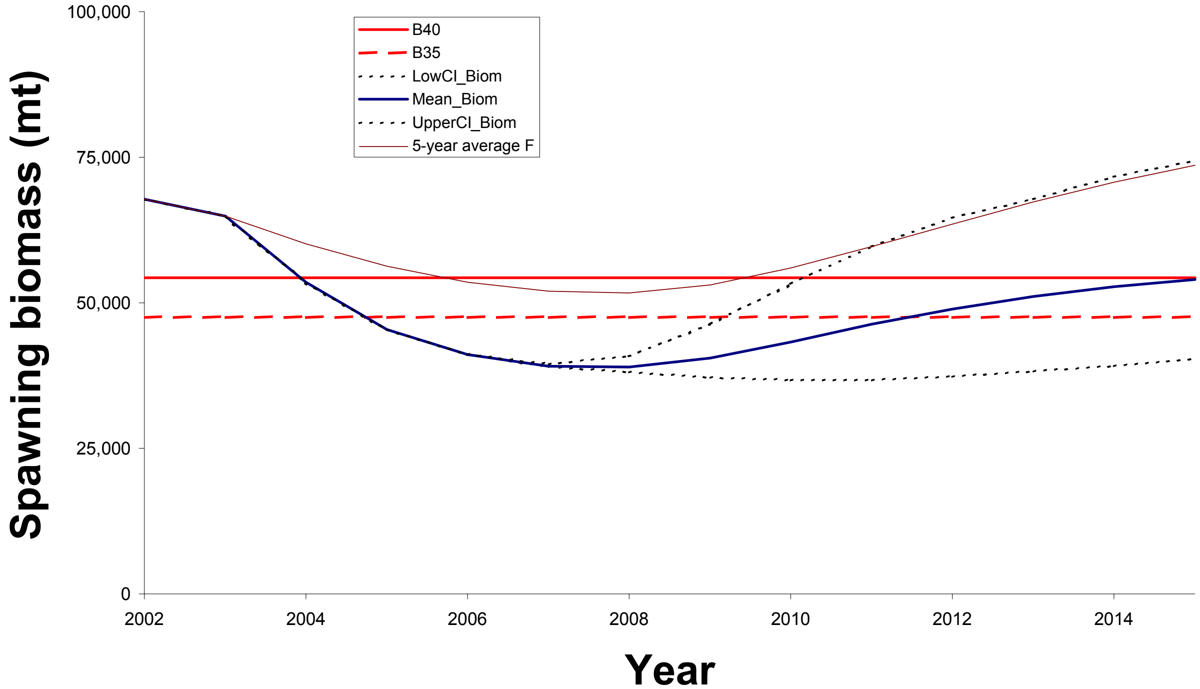

Figure 4.11. Stochastic trajectory of Greenland turbot female spawning biomass and projected levels for the maximum allowable fishing mortality rate under Amendment 56/56, Tier 3 and showing the mean expected value fishing under a constant *F* based on the recent 5-year average. These runs assume (conservatively) that the relative fishing mortality rates between longline and trawl fishing gear are equal. The dotted lines represent the upper and lower 90% confidence limits.